

Science Priorities *for the* Human Dimensions *of* Global Change

SCIENCE PRIORITIES FOR THE HUMAN
DIMENSIONS OF GLOBAL CHANGE
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Committee on the Human Dimensions of Global Change
Commission on Behavioral and Social Sciences and Education
National Research Council

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Preface

In the years since the creation of the International Geosphere-Biosphere Program, the international scientific community has come to accept that an understanding of global environmental change requires a focused and sustained consideration of its human dimensions—the effects of human activity on large physical and biological systems, the impacts of environmental change on people and societies, the responses of social systems to actual or anticipated environmental change, and the interactions among all these processes. At the request of the National Science Foundation, in 1989 the National Research Council established the Committee on the Human Dimensions of Global Change to assess knowledge relevant to these issues and develop a research agenda for the field. The committee published its findings in a 1992 book entitled *Global Environmental Change: Understanding the Human Dimensions*.

Since the release of that report, the committee has functioned in an advisory capacity to the U.S. Global Change Research Program (USGCRP) and to the Human Dimensions of Global Environmental Change Programme of the International Social Science Council. The U.S. and international research programs have continued to mature, and the U.S. program in particular has begun to grow more rapidly in response to the government's increasing interest in gathering policy-relevant scientific knowledge.

This report responds to the recent expansion of the USGCRP's scope to emphasize policy-relevant knowledge, much of which must come from research on human-environment interactions, the area of the committee's advisory responsibility. To provide intellectual guidance to this expansion of the program,

the committee identifies five science priorities—areas in which incremental, focused effort can be expected to yield particularly high returns of policy-relevant knowledge in the near term. It also defines a process through which a broad spectrum of members of the relevant communities of scientists, research sponsors, and consumers can develop these priorities into detailed science plans and implementation plans.

The research programs outlined here will contribute substantially to the U.S. government's stated goals of conducting "end-to-end (integrated) assessments of global change issues" and engaging in policy-relevant analyses of mitigation and adaptation strategies. They will complement the large, ongoing programs of research on earth system processes by building knowledge in other areas that must be integrated with knowledge of those processes to inform policy choices. As a result, these human dimensions programs will produce a solid base of knowledge on which to build future policy analyses.

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Oran R. Young, *Chair*
Committee on the Human Dimensions
of Global Change

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Defining Research Needs

The federal government in 1993 adopted a more proactive attitude in environmental policy in general and in global environmental policy in particular. This policy change has led the government to undertake a major expansion in the scope of the U.S. Global Change Research Program (USGCRP) to tighten the links between the basic science of global environmental change and the demands of policy makers for knowledge to inform their decisions. *Our Changing Planet: The FY 1994 U.S. Global Change Research Program* (Committee on Earth and Environmental Sciences, 1993) describes the program change as follows:

[T]he goal of this program expansion is to enable the U.S. government to conduct end-to-end (integrated) assessments of global change issues upon which sound policies can be identified, adopted, implemented, and maintained at regional, national, and international levels. End-to-end assessments will require the integration of basic research on Earth System processes with that on environmental and socio-economic impacts and effects studies and research on mitigation and adaptation strategies and technologies.

“Global change,” in the context of USGCRP, is usually understood to include global climate change, stratospheric ozone depletion, and loss of global biological diversity; other environmental changes that take place systematically at the global level, or that have global effects cumulatively, are sometimes included. Because integrated assessment requires a strong base

of knowledge about various kinds of human-environment interactions, the USGCRP agencies plan to increase significantly their support for research in areas relating to the human dimensions of global change. This report is addressed primarily to those U.S. government agencies. It begins a process by which advice from the relevant scientific communities can inform the agencies' decisions about research priorities that support the new policy priorities. We identify a few areas in which, in our judgment, focused incremental research efforts have the potential to yield significant increases in knowledge in the relatively near term that will contribute to the goal of improved integrated assessment. We also recommend a process for developing science plans and implementation plans for the future development of research in these areas.

The decision that research should serve the need for integrated assessment implies that a criterion of practicality will be applied in research policy decisions. This report applies that criterion to identifying the knowledge that decision makers need about the environmental and social processes that the society may wish to anticipate, influence, or adapt to.

Integrated assessment poses a major scientific challenge because it calls for the parallel and coordinated development of four kinds of research, only one of which has been a central focus of the U.S. program in the past.

1. *Research on earth system processes* has been the centerpiece of the USGCRP from its inception.

2. *Research on ecological and socioeconomic impacts and effects* of global environmental changes is a new emphasis of the program. Processes of human adaptation are central to research on impacts. The impacts that societies and their vulnerable subpopulations actually experience depend on the extent to which they can anticipate or adapt quickly to large or rapid environmental changes. Consequently, impacts research requires assessment of the vulnerability and of the robustness of social systems in the face of plausible large or rapid environmental changes. For example, the socioeconomic impact of a climate-induced drought will depend in part on the ability of social institutions to reallocate water supplies. Chapter 5 describes a recommended research focus on impact and vulnerability research; Chapters 2 and 6 recommend research foci that will develop needed knowledge on vulnerability and robustness.

3. *Research on policy options for mitigation and adaptation* and on their costs and benefits is another new and difficult area. In order to analyze costs, benefits, and policy implementation processes, policy analysts require projections of the social and economic conditions under which a policy will have its effects. For example, if population growth and increasing affluence result in increased strain on the world food production system in the future, climate changes that occur a generation from now might have

high costs in the absence of policy interventions in the interim. Chapters 3 and 4 recommend research foci that analyze policy options for mitigation and adaptation. Chapters 2 and 6 recommend research that would improve the projections of social and economic conditions used in policy analysis.

4. *Research on methods for the integration of knowledge* is the fourth type of research in the expanded U.S. program. Integrated assessment requires the development of methods for integrating knowledge that are sensitive to the fact that knowledge is more uncertain in some fields than others and to new developments in each area of knowledge to be integrated. It also requires building bridges between the worlds of scientists and policy makers. We address methods of knowledge integration indirectly at several points in the report, and we intend to address this issue more directly in the future.

For the USGCRP to yield the knowledge needed for integrated assessment and to inform policy choices, each of these kinds of research is critical. Particularly important are projections of the social and economic impacts of future environmental changes, including analyses of the vulnerabilities of subpopulations. Such projections are valuable for comparing the costs of various policy options; evaluating policy options on sometimes neglected dimensions, such as how they will affect future demand for critical resources, future ability to adapt, and the vulnerability of subpopulations; and considering which policy options provide the best insurance against a variety of plausible environmental surprises.

The term *integrated assessment* is sometimes used in a restricted sense, to refer only to the use of methods for integrating knowledge. We emphasize the importance of construing the research needs more broadly than that, because the value of improved methods for knowledge integration is inherently limited by the accuracy or uncertainty of the knowledge to be integrated. To achieve the purpose of the program expansion, it is necessary to strengthen scientific capabilities within the U.S. program, for example, in the areas of impact analysis, mitigation and adaptation, vulnerability analysis, and social and economic projection. This report identifies research foci that can build those capabilities.

The program expansion challenges the scientific community and the agencies that implement it to develop knowledge simultaneously in several major substantive and methodological areas that are new to the program. The challenge is increased by the fact that each of these new areas depends on knowledge about the human dimensions of global change, a relatively underdeveloped sector of the USGCRP. The expansion also requires the integration of social science research with the natural science research that has until now formed the core of the U.S. program. This kind of integration

has been difficult in the past because of major structural barriers both in academia and government (National Research Council, 1992: Chapter 7).

FIVE RESEARCH PRIORITIES

The recent expansion in the scope of the USGCRP implies new research needs. In response, this report identifies five new priorities for research on the human dimensions of global change. We particularly emphasize research to improve basic knowledge essential for integrated assessments—knowledge that illuminates the ways social processes and institutions shape, respond to, and are affected by environmental change and the ways they interact with mitigation and adaptation policies. We have selected these particular research foci after considering several careful reviews that have identified major conceptual categories and developed lists of themes worthy of study in this field (Human Dimensions of Global Environmental Change Programme, 1994; Jacobson and Price, 1990; National Research Council, 1990a, 1992). We have paid particular attention to a draft white paper from an interagency group within the USGCRP (Cantor, Houghton, Kane, Scheraga et al., 1993), which makes reasonably broad suggestions of future directions on the basis of current activities within the program. We consider our recommendations to be an elaboration and focusing of ideas raised in the draft white paper.

We considered the many fields outlined in these agenda-setting documents in the light of the ongoing and expanded needs of the USGCRP and of other decision criteria (Table 1). A list of possible priority areas was generated from these documents and from individual committee members' nominations and narrowed on the basis of a straw ballot and detailed discussion within the committee. The areas we have selected are those in which, in the judgment of the committee, incremental research efforts will be most effective in terms of building on existing work; contributing to the wider priorities and needs of the U.S. program, particularly for building the capacity for integrated assessment; and producing useful results in the next few years. We have also considered other criteria, including the ability of new research to link to natural science research programs within the USGCRP and to international research activities.

Judged against the need for knowledge, the human dimensions of global change is a drastically underfunded field within the USGCRP. We believe that the ongoing work on human dimensions within the program is, in general, highly important and worthy of continued support. However, significantly increased human dimensions research will be required if the USGCRP is to attain its research objectives, particularly its newly identified objectives in the areas of impact analysis, analysis of mitigation and adaptation options, and integrated assessment. We recommend carefully chosen

TABLE 1 Selection Criteria for Priority Research Areas

1. *Area contributes to expanded USGCRP priorities.* New federal priorities, reflected in *Our Changing Planet*, imply expanded efforts in the areas of human impacts analysis, analysis of mitigation and adaptation response options, and the integration of these two kinds of information with information on earth system processes.
2. *Area is recognized as important by the wider global change scientific community.* Research will make clear links to climate change, ozone depletion, or biodiversity; it is likely to improve understanding of the trajectory of global changes, estimates of impacts, or elements of global change models.
3. *Area can be matched with a federal agency or set of agencies capable of managing it.* We have recommended involving federal mission agencies in research on the human dimensions of global change, but have also pointed out that the obvious agencies do not always have the necessary expertise (National Research Council, 1992). Priority areas will fare best if there is an agency or agencies to nurture them.
4. *Area is defined so as to encourage interdisciplinary work among the social sciences.* Other things being equal, areas that foster interdisciplinary cooperation are preferable because they build lines of communication that will enhance future research.
5. *Area builds on strengths of the human dimensions research community.* Starting from strength increases the likelihood of producing useful results soon.
6. *Area links to international research activities.* This primarily means the core program areas of the Human Dimensions of Global Environmental Change Programme of the International Social Science Council, but it may also refer to core areas of the International Geosphere-Biosphere Programme. International links multiply the value of U.S. research by building on work and funding from other countries. They also strengthen the U.S. contribution to international research efforts.
7. *Area links to issues of sustainable development.* The U.S. government concern with identifying ways to maintain economic growth without compromising environmental quality implies a need for research on how different paths of development affect demands on the environment. This need in turn implies a need for studies of the driving forces of global change.
8. *Area would foster social science-natural science research collaboration.*
9. *Area requires a global focus including both the developed and developing worlds.*

areas in which an incremental investment in focused research is likely to yield particularly great near-term dividends.

We consider each of the following research areas to be of major importance for development by the USGCRP:

Understanding Land Use Change

Improving Policy Analysis: Research on the Decision-Making Process

Designing Policy Instruments and Institutions to Address Energy-Related Environmental Problems

Assessing Impacts, Vulnerability, and Adaptation to Global Changes

Understanding Population Dynamics and Global Change

We have defined most of these topics in terms of concrete problem areas rather than in terms of cross-cutting categories such as "mitigation" or "integrated assessment." A problem-focused approach ensures that techniques of knowledge integration will be put to practical test. It also ensures that integrated assessment will address the issue of levels of analysis. Whereas global climate models are developed on a planetary scale, policy decisions are defined by political boundaries; a focus on particular practical issues will force communication between analyses at different levels. The chapters that follow explain how each research area will contribute significantly to the government's ability to conduct integrated assessments of its policy options regarding global change.

NEXT STEPS

Although all of these topics (and others) should be developed quickly, limited human resources dictate that one science plan be developed at a time. In our judgment, a science plan for land use change should be developed first for the simple reason that the scientific community has made the most progress toward such a plan in this area. Land use change provides a concrete focus for integrated analysis of human activities, earth system processes, and human responses. It is an area in which data bases are being developed rapidly for policy analysis and knowledge integration.

What is needed now is a strategic planning process capable of singling out particularly promising research priorities and developing both science plans and implementation plans to guide work relating to each priority. Long familiar to natural scientists (e.g., National Research Council, 1983, 1990b, 1993), this process of strategic planning is less common in the social sciences. The plan we propose follows the pattern used to develop several natural science research areas within the GCRP.

A science plan begins with the identification of a large thematic topic (for example, the El Niño effect, world ocean currents, biogeochemical

fluxes) deemed ripe for concentrated attention on the part of the scientific community over a period of 5 to 10 years. It then proceeds to spell out: (1) what is already known about the topic, (2) the major unknowns about it, (3) which of these unknowns are most ripe for focused attention, (4) what data will be needed to come to terms with these unknowns, and (5) what benefits can be expected from a focused research effort. A typical science plan will include a statement of milestones describing expectations about results likely to become available in the topic area in 2 years, 5 years, and 10 years if the plan is followed.

An implementation plan picks up where the science plan leaves off: it spells out the practical steps required to transform the science plan into a working program. It indicates the resources required to carry out the science plan, discusses the appropriate mix of investigator-initiated and targeted research, suggests ways to handle logistical needs, and lays out procedures for pooling and exchanging data among program participants. Implementation plans frequently include organizational arrangements, such as the creation of a scientific steering committee or executive committee to ensure proper communication among the sizable group of principal investigators involved in the program. An implementation plan might also deal with the issue of whether to create one or more national centers funded on an ongoing basis to ensure concentration and continuity over time in dealing with a well-defined program area.

This report does not propose science plans or implementation plans for the five recommended areas of focused research because we believe that such plans should be developed through broader participation of the relevant communities of research producers and users. Rather, this report identifies the areas in which science and implementation plans are most urgently needed, explains the need for focused research in those areas, outlines the substantive scope of each area and the likely gains in knowledge, and raises key issues to be addressed in developing the science and implementation plans.

In the case of land use change, the committee proposes the following specific process to develop credible science and implementation plans covering research over a 5-10 year period:

Step 1: The committee will establish a writing group to prepare a draft science plan dealing with land use change for consideration by the wider scientific community, funding agencies, and potential users of the research.

Step 2: The committee will convene one or more workshops to gather reactions to its initial draft from a wide range of constituencies.

Step 3: An expanded writing group will revise the draft science plan in response to the workshops.

Step 4: The revised science plan will be reviewed by the workshop participants.

Step 5: The writing group (reconfigured as appropriate) will prepare an implementation plan for a 5- to 10-year program of research on land use change.

Step 6: A steering committee or executive committee will be created to guide and regularly review the program over the course of its life.

We anticipate that such a science plan for research on land use change will take six months to develop; the development of an implementation plan would take another six months. Once this process is well defined, efforts should be focused on the timely development of science and implementation plans for the other topics on the list. At this juncture, we believe the second topic to go through this strategic planning process should be research on decision making and global change. At each stage, it will be important to provide opportunities for those representing the concerns of the science community, the funding community, and the policy-making community to consider adding new science priorities to the initial list and to reconsider the sequence in which these priorities go through the strategic planning process.

Understanding Land Use Change

Our first priority is to develop a science plan for research on land use change. Changes in land use are among the important forces driving global climate change. Climate change can also be expected to have an important impact on land use change. But it is the context within which land use change is occurring that gives it special importance. The forces that determine the trajectory of land use change will affect not only the natural environment, but also the human consequences of climate change—both its socioeconomic impacts and the policy options available for mitigation and adaptation. For example, the impact of climate change will depend on changes in land use occasioned by growing demand for agricultural commodities, human habitation, and the preservation of natural habitats.

By the middle of the next century, the demand for agricultural commodities—primarily food—will rise by a multiple of 3 to 4 at the global level. Population growth alone may cause an approximate doubling of the demand for the products of agriculture. But even moderate growth in income in the developing world will add at least as much to increases in demand as population alone—thus increasing demand to at least 3 times the present level. Those increases must be achieved in an environment of increased competition for land—for human settlement, transportation, biomass production for energy, preservation of biodiversity, and expansion in the supply of environmental amenities.

An important implication is that we must anticipate substantial intensification of human activities on land currently devoted to agricultural pro-

duction. Unless this intensification is addressed by new technologies that are not now in the pipeline, we can expect additional impacts on global climate change from land use conversion and intensification—for example, use of nitrogen fertilizer may increase by a factor of 6 to 10. This and other increased material inputs into agricultural production will have environmental implications that are not yet well understood, but that are likely to include impacts on global environmental systems. In addition, as agricultural intensity increases, the effects of any environmentally induced changes in the productivity of agricultural lands will increase proportionally; and to the extent that nonagricultural demands on the land also grow, options for responding to those effects will be limited. For these reasons, it is important to understand the linkages of agricultural and other demands on land, land use change, and changes in agricultural and industrial metabolism or ecology.

The role of market forces in land use change for the production of agricultural commodities has long been a subject of substantial research. The issue of land use and supply response was an active field of research in agricultural economics and development economics from the mid-1950s through the 1960s (Krishna, 1967). There is also a literature on the relationships of population change and land use change in the tropics (Grainger, 1992; Jolly and Torrey, 1993).

Efforts to estimate global demand for agricultural land depend on data on market forces and population. But because these data often exist only at the national level and above, it can be difficult to model processes at the subnational (regional and local) levels, where actual land use change is taking place. There, a wide variety of social, political, and cultural institutions mediate the pace and character of land cover conversion for human use, the interaction of market and nonmarket influences, and the influence of national and international policies. In order to understand the driving forces of land use change at the global level, it is essential to know the mechanisms and dynamics by which land use managers at the local level govern land. That includes analysis of land use institutions, assessment of short-term biophysical constraints and feedbacks, and cross-scale macroeconomic and macropolitical influences involving markets and states.

RELATION TO USGCRP PRIORITIES

A focused research effort on land use change will support the wider needs of the USGCRP in at least the following ways:

- by improving forecasts of the future status of land cover and thus changes in the earth's albedo and other physical parameters affecting climate change;

- by improving forecasts of land uses that affect the earth's biogeochemical cycles;
- by improving forecasts of future land uses that will bear the impacts of climate changes, thus putting analysis of the ecological and human consequences of climate change in the context of likely future terrestrial, social, and economic conditions; and
- by providing more realistic estimates of the costs and benefits of mitigation and adaptation options based on likely future conditions of land use and of demand for land and agricultural commodities.

TIMELINESS OF EFFORT

Focused research on land use change is particularly timely now for at least the following reasons:

- recent developments in geographic information systems, including projects to include georeferenced social data, make possible analyses that could not have been done before;
- modeling projects using geographic information systems can help select from among feasible priorities for other kinds of research those most likely to decrease key uncertainties in understanding;
- the International Geosphere-Biosphere Programme (IGBP) and the Human Dimensions of Environmental Change Programme (HDP) are in the process of developing an organized international scientific research program in this area, and an effort to focus research within the United States now would both assist the international effort and leverage that effort to strengthen work being done domestically; and
- a focused research priority in this area would help coalesce the growing interest in human dimensions research within agencies that have not previously been major contributors to the USGCRP (e.g., the Department of the Interior, the Department of Agriculture).

RESEARCH GOALS

The following are among the several issues on which research might be expected to make significant progress in the short term (2-5 years) and longer term (10-20 years).

Short Term

1. Analyses of the roles of market forces, population pressures, property rights institutions, and technological change in land cover conversion from primary forests, grasslands, and other critical land cover types.

2. Analyses of the role of economic and institutional incentives for reconversion of degraded agricultural and forest lands, as well as the impact of existing protected areas in regional-scale land use and land cover dynamics.
3. Analyses of opportunities for and constraints on reducing emissions of greenhouse gases resulting from agricultural land use practices (e.g., methane from rice fields, nitrous oxide from fertilizer use).
4. Analyses of the sources of differences in urban density across regions and of changes in urban density within regions; implications of urban-rural linkages and intensification for land use conversion.

Longer Term

1. Continuous monitoring of land use, land cover, and land use technologies is needed to generate evidence required to improve understanding of land use change. Monitoring should cover spatial units that are sufficiently flexible to be useful for environmental (including remotely sensed) data as well as socioeconomic and demographic data. Particular attention should be given to change in technologies involved in land use since the capability to improve production while protecting environmental quality is, to a significant extent, a function of technology.
2. Analyses of economic, cultural, and biological implications of changes in biodiversity.
3. Analyses of the political and economic viability of policies and institutional design for adaptation and mitigation strategies in areas such as (a) coastal resource use and (b) transfer of water resources from low value to higher-value uses.
4. Models linking the mechanisms and dynamics of anthropogenic land use changes to biophysical modeling efforts. These would include models of land use "transformation in . . . tropical forests and coastal wetlands . . . to provide regional forecasts of the impact of human activities on the extent of the affected land uses over decades-to-century scales" (National Research Council, 1990a:118). In these environments, land transformation can be both a source and a consequence of global change. Model construction would be designed to analyze the sensitivity of land use and land cover changes to two broad categories of policy regimes: (a) those that rely primarily on market or market-like incentives and disincentives (i.e., those that operate through the price mechanism) and (b) those that rely primarily on regulatory (command and control) approaches.

Further identification and selection of research objectives would be made in the process of developing the science and implementation plans for this area.

RELATION TO INTERNATIONAL RESEARCH

A Land Use/Land Cover Core Planning Project is now being developed under the HDP and the IGBP with B.L. Turner and David Skole serving as cochairs. This research effort is designed to answer three questions:

- How has land cover been changed by human use over the past 300 years?
- What are the major human causes of land use change in different spatial (and temporal) contexts?
- How will global environmental changes affect land use and land cover?

The international effort will emphasize three interrelated activities: a global-to-national modeling effort, an empirically generated local-to-national modeling effort (both of these are organized consistently with the research directions recommended above), and a data generation component intended to link socioeconomic data at the global and national levels to land cover and other biophysical classification and data efforts, such as the IGBP Data and Information System.

The substantial involvement of U.S. researchers and research institutions in the creation of the international research program and the natural complementarity of the U.S. and international research efforts on the human dimensions of global change make it important that the USGCRP science plan in the area of land use change draw on and reinforce the IGBP/HDP effort.

IMPLEMENTATION ISSUES

The research program should represent a mix of institutional support and project support for investigator-initiated research. The case for investigator-initiated research rests on the potential for advancing science and methods related to analysis of the sources and consequences of land use change. The case for institutional support rests on the need for a core budget commitment for long-term research on issues of strategic importance. (An example from a closely related field is the multiyear effort led by John Krutilla and Allen Kneese at Resources for the Future to develop methods for valuing unique environments and estimating the costs and benefits of limiting the spillover of residuals from agricultural and industrial production.) The case for institutional support is particularly strong when the research requires modeling efforts based on the analysis of large georeferenced data sets.

The science plan should be developed in the context of considering the

center(s) for human dimensions of climate change that Congress has called for establishing in 1995, because such center(s) could play an important role in land use change research. The implementation plan should clarify the roles of research in centers, contracts or cooperative agreements between centers and individual researchers, research supported directly by agencies, and the networking function of centers for linking investigator-initiated research with the center-based research.

The proposed research on land use change should be a significant part of the U.S. human dimensions research program. One should not underestimate the costs of conducting research that is intended to become policy relevant. An objective must be to identify not only the driving forces and the existing relationships among them and changes in land use, but also the mechanisms explaining those relationships and the variables that can be manipulated to achieve desired policy goals. Research focused on global change consequences and options in the land use area must include careful attention to the fact that agents anticipate such changes and respond, rationally or otherwise, to anticipated changes and to anticipated policy responses.

3

Improving Policy Analysis: Research on the Decision-Making Process

Scientific research is of little practical value if it does not address the issues that matter to decision makers and reach them in a useful form. Failure to demonstrate practicality can threaten support for research programs whose budgets are justified by policy concerns. That burden of proof must be borne not only by the more directly applicable research (e.g., short-term impact assessments), but also by the fundamental research designed to support applications. Fundamental research should provide decision makers with the information needed for long-term planning, by indicating the extent of existing uncertainties and the rate at which they might be reduced.

Concern for the practicality of environmental research was a focal topic in the committee's 1992 report (National Research Council, 1992) and a more recent report prepared for Congress (U.S. Congress, Office of Technology Assessment, 1993). Such concern underlies the expansion of the USGCRP to promote integrated assessment and recent planning on the human dimensions component of the USGCRP (Cantor et al., 1993). The practicality of global change research depends on bridging the gap between decision makers, who need answers about how global change might affect their decisions and how their decisions might affect global change, and scientists, who create knowledge about global change that ideally provides the answers that decision makers seek. This gap is a normal consequence of the differing priorities of decision makers and scientists, and it does not resolve itself automatically. We believe that global change research is an area in which the gap is particularly problematic and that it is likely to remain a source of difficulty for the research program unless special efforts are taken.

Consequently, we see bridging the gap as a critical research problem. We propose a systematic research program, building on work already done in the field (Fischhoff and Furby, 1983; Fischhoff, Svenson, and Slovic, 1987; Rubin, Lave, and Morgan, 1992), to help ensure that relevant environmental science is conducted and that its results are provided to decision makers in usable form.

Aspects of these problems recur in all decisional domains in which large, autonomous research programs have developed around major policy issues (e.g., AIDS, health care reform). Global change, however, presents an extreme degree of complexity and uncertainty. Not only is the relevant scientific knowledge imperfect, but also a considerable effort is needed to assess the extent of its uncertainty. Moreover, it is characterized by well-publicized disagreements among specialists, whose respective credibility is difficult for decision makers to

In such a situation, special efforts are needed to enhance mutual understanding between the producers of knowledge about global change and the consumers of that knowledge. Better communication will guide scientists toward producing more useful knowledge and decision makers toward making better use of what is produced.

We do not believe that effective communication will occur merely as a result of exhortation to try harder and a commitment to doing so. But systematic research using methods from decision theory and related fields can help by specifying the sources of communication failures and offering methods for bridging the gap (Raiffa, 1968; von Winterfeldt and Edwards, 1986). We propose a research program to improve global change decision making by building on systematic analyses of particular decisions and decision contexts. The research program would include both formal and descriptive analyses and would require participation of all the social and natural sciences needed to characterize particular decisions, as well as representatives of the decision makers.

Research would begin from the recognition that a body of scientific knowledge may be relevant to decision makers operating at quite different levels. For example, decision makers who need answers to questions about the potential for coastal zone flooding include homeowners, municipal officials, managers of Superfund sites in coastal zones, developers, local citizens' groups, Federal Emergency Management Agency officials, and flood insurance providers. These decision makers will vary in what issues interest them and what level of detail they require. Estimates of sea level rise and storm surges will be particularly relevant to decision makers with long time horizons, such as regional planners, investors in fixed capital equipment, and insurers. In order to be useful to such a range of decision makers, scientific knowledge needs to be developed and delivered with their needs in mind.

Analyses of decision needs will typically show that for some decisions environmental science is relevant, whereas for others it is not; that scientific knowledge that is relevant today may not be relevant later (and vice versa);

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that the future relevance of knowledge will depend on the policies that are pursued in the interim—some of which will be affected by current research. Analyzing these possibilities requires intimate knowledge of both the decisions and the relevant environmental science. Without that link, decision making will suffer, by being deprived of relevant results, and environmental science will suffer, by being less able to make the case for its usefulness.

RELATION TO USGCRP PRIORITIES

A focused research effort on decision making and global change will support the wider needs of the USGCRP in at least the following ways:

- it will support the development of methods for integrated systems assessment, as planned within the human dimensions segment of the USGCRP, by connecting those assessments with specific decisions;
- it will assist the wider USGCRP initiative on integrated assessment by developing ways to translate decision makers' questions into priorities for global change research;
- it will complement research on the economics of global change (e.g., work on the value of global change information) with a perspective that addresses a wide range of decisions as well as identifying barriers to effective decision making; and
- it will establish communication channels between the environmental sciences and decision makers, leading to the better use of existing science and better focus for future science.

TIMELINESS OF EFFORT

Focused research on decision making and global change is particularly timely now for at least the following reasons:

- developing methods for integrated assessment and improving links between research and policy have assumed pressing importance within the USGCRP;
- techniques of decision analysis, not widely used now within the USGCRP, are available and relevant; and
- a decision-making perspective provides a reasoned and orderly framework for the environmental sciences to address the increasing demands for accountability, by demonstrating the practical differences that the results of their research make.

RESEARCH GOALS

Research would address such issues as:

- What are the specific details of the decisions that various actors face with regard to anticipated global changes? What options do these decision makers perceive (and overlook)? How well do they understand the consequences of those actions? What weight do they assign to different consequences? What time frame do they consider? What do they extract from reports of scientific findings? What cognitive, political, cultural, and institutional factors shape their thinking about decision alternatives or constrain their decision making?
- How can research be assigned priorities according to its potential value to different decision makers?
- How do decision makers' information needs depend on the level of aggregation of the information and the scope of their decisional power?
- How can complex data be summarized in ways that are faithful to the underlying science and pertinent to decision makers? How can scientists assess the limits to current knowledge and the opportunities for reducing uncertainty?

The box (opposite page) suggests one research approach that may be used in various decisional domains, such as land use, energy policy, and the evaluation of environmentally benign technologies. In this approach, an actual set of decisions is analyzed so as to describe the decisions as seen by key decision makers, relate them to available knowledge, identify the gaps between the two, and present the scientific community with an analysis of those gaps. A goal of each project in the decision-making research area would be to show how pending research can best be directed to address decision makers' questions. Each project would consider the variety of decision makers (e.g., officials of national, state, and local governments and international organizations, corporate executives, households, leaders of nongovernmental organizations and social movements) that influence policy, the potential conflicts among them, and the institutional obstacles to effective action (e.g., perverse incentives, jurisdictional obstacles). In addition to providing insight into the relations of science and policy in particular domains, the projects would identify research needs in the social and decision sciences. Over the long term, the research would develop general methods for improving the match between scientific production and decision makers' needs. That effort would require fundamental research on such topics as: (a) the cumulative effects of imperfections in individual decision making on societal processes, (b) procedures for eliciting scientists' beliefs regarding the definitiveness of their research, (c) procedures for comparing environmental outcomes with other (e.g., economic) impacts, (d) methods for determining people's current and desired time horizons, (e) factors that shape decision makers' ways of thinking about their decisions, (f) analytical procedures estimating the practical

IN-DEPTH ANALYSIS OF GLOBAL CHANGE DECISION MAKING

One strategy for decision-making research is to analyze in depth a suite of inter-related decisions in which a global environmental change (and the associated sciences) play a central role. Examples include decisions about land use, energy policy, the implementation of market and price-based mechanisms to secure sustainable development, the evaluation of environmentally benign technologies, and the quantification of environmental effects.

The initial research goal would be to create detailed descriptions of the decisions faced by key decision makers in a particular domain. To fully understand the dynamics by which decisions are made, the full range of participants in a decision-making process will have to be considered. The key decision makers will vary from one context to another but will typically include government officials at various levels, corporate officials, leaders of social movements, and members of the public. The descriptions would incorporate the perspectives both of the decision makers and of expert observers of their circumstances. At the core of each description would be alternative characterizations of the decision, in decision analytic terms, created with sufficient precision to allow formal analyses. Surrounding this formal core would be narrative accounts of the assumptions made in creating the analytical characterizations, the weaknesses in these representations, and the issues that are omitted altogether.

The second goal of each example would be a systematic analysis of the implications of existing environmental research for these specific decisions. That analysis would begin by identifying discrepancies between expert and decision maker perspectives on the decision. It would proceed to a diagnosis of the reasons for the existence of these disagreements, accepting the possibility that both perspectives might be in error. The analysis would continue by evaluating the impacts of bridging the gaps by providing better scientific information, including summaries of research in decision-relevant terms. Given the reporting conventions of most sciences, this step would involve eliciting judgmental assessments from substantive experts, in addition to reviewing published studies. An estimate of the potential usefulness of existing research could then be derived by comparing the expected value and definitiveness of decisions taken with and without the benefit of various results.

The research would then pose the informational needs of decision makers to environmental scientists, asking what they could do to satisfy those needs. Scientists' answers might include both new projects and the reworking of existing data. These scientists would be asked to focus on both short-term and long-term projects. The emphasis would be on usefulness of research results for specific decisions and not just their general ability to inform. Attention would also be directed to the fundamental research needed to achieve decision-relevant results. However, the inferential chain would have to be laid out explicitly (e.g., we need to build *x*, in order to learn *y*, which will help *z* to decide whether to take action *a* or action *b*). In addition to its substantive results, the process would also help the individuals involved learn to speak to one another.

yield of possible research programs, and (g) ways for setting priorities among scientific information in terms of its practical usefulness.

RELATION TO INTERNATIONAL RESEARCH

There is currently no comparable international research effort. There are, however, decision scientists in most of the Western democracies and the former Soviet bloc who could conduct comparable research. An international effort would help in judging research priorities in terms of the needs of foreign, international, and transnational decision makers.

IMPLEMENTATION ISSUES

At least initially, this research should be done in interdisciplinary teams, involving both natural and social scientists, with the latter in a lead role. A strong argument can be made for much of this research to be conducted by groups in individual institutions with long-term support because of the difficulty of creating a comprehensive perspective on the decisions being studied, as well as a common language among the participants. There would also be possibilities for smaller investigator-initiated projects. Each might pursue issues that are neglected by the larger teams, fundamental research topics that have emerged from them, and applications in new domains. In the interests of transfer of technology, researchers involved in major research projects should develop working relationships with relevant agency personnel.

Designing Policy Instruments and Institutions to Address Energy-Related Environmental Problems

Global climate change and other global and regional environmental changes are intimately tied to energy use, particularly the combustion of fossil fuels, in ways that hardly need elaboration. A significant effort to study energy and global change is already under way within the USGCRP, and we believe this is important work. We also believe, however, that it should be supplemented by work focusing on questions of institutional design, including design of policy instruments, because institutional issues are critical to mitigation and adaptation in the energy system, essential to policy analysis, and underrepresented in the current research effort. Institutional design issues are critical as well to other important global change issues, such as water management in response to global change and understanding of the rapid increase in nitrogen fixation by human activities. Thus, knowledge gained in the study of institutions, including policy instruments, to address energy-related environmental problems will have value when transferred to other environmental problems.

RELATION TO USGCRP PRIORITIES

The importance of a focused effort on energy use is already well recognized within the USGCRP. A focus on institutional design is critical to the new USGCRP emphases on analysis of mitigation and adaptation options and integrated assessment because response options must be evaluated in the light of institutional and cultural barriers and opportunities affecting their feasibility and mediating their effectiveness. Various policy instruments designed to produce simi-

lar mitigation or adaptation patterns may in fact lead to quite different ancillary impacts and quite different patterns of uncertainty in responses. Economic and regulatory interventions, for example, rarely operate in practice as well as is suggested by institution-free theories. Their effects depend on the cultural and institutional context of their implementation. Similarly, technological innovations are not readily adopted by all those who would benefit, and rates of adoption are sensitive to institutional variations. Thus, a research effort focused on institutional design issues can:

- improve estimates of the costs and benefits (including those associated with nonmarket goods and services) of the various options for mitigating and adapting to climate change through interventions in the energy system;
- improve integrated assessments of climate change by improving understanding of the likely outcomes of policy options; and
- identify response options that might not otherwise be considered.

Such a research focus would also gather basic knowledge about the operation of environmental management institutions affecting the energy sector that might be transferable to the analysis of options for managing nonenergy environmental problems.

TIMELINESS OF EFFORT

Focused research on institutional design for managing energy-related environmental problems is timely now for at least these reasons:

- the U.S. commitment to greenhouse gas reduction requires careful analysis of a full range of energy policy options;
- the USGCRP is moving ahead with economic analyses of some types of policy instruments, analyses that should be supplemented by institutional studies for greatest practical value;
- analysts are increasingly recommending institutional approaches to managing these problems (e.g., creation of emissions trading permit regimes), making institutional analysis particularly timely; and
- growing international communities of researchers who work on market-like and other institutions for the management of common-pool resources can now be drawn into the analytical effort.

RESEARCH GOALS

Research would address questions in the following areas:

1. What is the potential for mitigating or adapting to global environmental

changes that result from energy use by adopting policies aimed at different kinds of actors or at different levels in the energy system? Analysis would address such units of action and levels of analysis as governments, business firms, individuals/households, networks and coalitions, local communities, and collectivities of resource users.

2. What social dilemmas and other constraints act as barriers to appropriate individual, firm, collective, community, and government action? How can improved response options be selected taking this knowledge into account?

3. Who pays the costs of mitigation or adaptation under the various policy instruments and institutions? What are the effects of various response options on income distribution and other distributional considerations?

4. Under what conditions can various policy instruments be viable for mitigation or adaptation? Examples of instruments to be investigated include: emissions permits or other market-like instruments; price and tax setting; joint, bilateral/multilateral implementation of agreements; multilateral quantity restrictions; governmental suasion programs; technology demonstrations; dissemination of information; changes in property rights and governance systems; international commissions; markets for contingent claims; full liability for harm, enforced using legal systems; decentralized institutional approaches; educational, legal, and other supports for cultural paradigms affecting personal lifestyles and behavior; and combinations of market-like or other centralized instruments with decentralized, community, and culturally based systems of response.

5. How will different policy instruments influence the uncertainty about the various policy-relevant impacts? For example, emissions permits may greatly reduce uncertainty about the total quantities of emissions but increase uncertainty about the final costs of emissions reductions; "green taxes" may not greatly change the uncertainty about quantities, prices, or costs.

6. What effective roles can be played in energy management by decentralized, community-level institutions and grassroots action?

7. What are the characteristics of policies that effectively elicit innovations in energy technology and management within public- and private-sector institutions? For instance, what forms of public-private partnerships are most effective for this purpose? What policy approaches improve on prescriptive standards when these have slowed innovation? Under what conditions are inducements, such as promises of government contracts for the first innovator across an efficiency threshold, an effective stimulus to innovation? How is the effectiveness of policies influenced by market structures in energy industries?

8. What mechanisms can overcome the inhibitions to transfer of efficient energy technologies to developing and formerly Communist countries? One issue here concerns the risk-averse policy strategies of international lending institutions that favor investments in well-proven technologies over those that have not been proven in new settings. Another is that of designing something like an emissions permit trading regime that can work internationally.

9. How might cultural shifts affect the future viability and effectiveness of institutional design options (e.g., shifts in values and behavior at the individual and household level, shifting cultural paradigms of reference groups, the interaction of personal and cultural changes)? How might institutional changes (e.g., changes in property rights and governance) affect cultural and value shifts?

RELATION TO INTERNATIONAL RESEARCH

The HDP has identified two research programs related to this issue: (1) Impacts of Structures and Institutions and (2) Energy Production and Consumption. Both programs are in very early stages of development. A U.S. effort in this area would help the international programs define their directions. There are international research communities that could participate in such programs.

IMPLEMENTATION ISSUES

At this time, institutional studies of energy-environment issues are probably best conducted in multiple, low-cost, research projects. They require interdisciplinary groups that include (at a minimum) experts in policy analysis, the relevant energy technologies, and the relevant energy users and management institutions. The mix of disciplines should be dictated by the problem. Although the Department of Energy (DOE) and the Environmental Protection Agency (EPA) manage programs of economic research on global change, they will need to make special efforts to broaden their portfolios to include institutional research and to identify appropriate project managers for institutional studies. It is worth noting that some such studies have been done in DOE national laboratories. Although it makes sense for much of the research on this focused topic to be managed by EPA and DOE, management should not be limited to these agencies because important progress may come from researchers who begin from more basic theoretical questions about community resource management, property rights institutions, and the like. Other agencies, particularly the National Science Foundation, should support research on this topic.

Assessing Impacts, Vulnerability, and Adaptation to Global Changes

As the scientific understanding and forecasting of global change improves or transforms, there is a continuing need to review and revise what we know about the human consequences of these changes and the ability of social systems to adapt to them. It is also important to monitor the shifting vulnerability of human systems as political, technological, and economic trends and policies alter the conditions in which societies experience global change.

For example, improved forecasts of El Niño and better regional estimates of climate associated with global warming can be linked to updated assessments of the human impacts of climate variability and change. Demographic shifts and economic restructuring have dramatically altered the vulnerability of many regions to water supply variations and natural hazards. Adaptations such as irrigation and plant breeding are changing the ability of agricultural systems to cope with droughts.

Impact, vulnerability, and adaptation assessments can greatly benefit from new methods and data availabilities. For example, impact assessments can incorporate improved analyses of climate variability, uncertainty, and local geographical differences. Fresh datasets (such as decadal population and agricultural censuses, satellite imagery) within geographic information systems can enhance and update assessments.

RELATION TO USGCRP PRIORITIES

Focused research efforts on the consequences of global change can support the wider needs of the USGCRP in the following ways:

- by providing current and policy-relevant information on the impacts of various global change scenarios at regional scales;
- by contributing to assessments that integrate a range of scientific data and models with information on social impacts, vulnerabilities, and adaptations and their interaction with mitigation efforts;
- by providing insights into the ways in which (seemingly unrelated) policy decisions and societal conditions are changing the vulnerability of human systems to global change;
- by improving the ability to assess the societal impacts of interannual climate variability (such as El Niño) and the likely effect of improved forecasts and other responses; and
- by providing feedback to the modeling community as to the most appropriate and urgent data outputs (variables, time and space scales) for assessing the human impacts of global change.

TIMELINESS OF EFFORT

This research priority is timely because of its potential contribution to the USGCRP's increasing emphasis on consequences, sustainability, and integrated assessment. There is a considerable community of researchers with experience in assessing the impacts of climate change. This community can be supported in work to improve methods, datasets, and models that can use the results of new generations of climate models (both general circulation and mesoscale).

RESEARCH GOALS

Research on impacts, vulnerability, and adaptation to global changes can yield:

- improved and more regionally detailed assessments of the impact of climate change on socioeconomic and ecological systems using the most recent results of general circulation climate models, mesoscale models for global warming, and information on the characteristics of interannual climate variability;
- vulnerability assessments of the ability of resource and human systems such as forestry, agriculture, cities, and industry to anticipate and respond to global changes (taking into account the ways in which major nonenvironmental changes such as population growth, institutional and economic transformations, and technical developments are altering the vulnerabilities of individuals, communities, and regions to environmental change and variation); and
- improved information for valuing the consequences of global change, incorporating estimates of uncertainty in decision processes and providing key transfer functions (e.g., the relationship between temperatures and health or water resources) for economic and social impact assessments.

This research should build on developments in remote sensing, geographic information systems, and the availability of large social science datasets. It should emphasize comparative research to take into account institutional differences, such economic processes as the regionally redistributive effects of global change, and shifts in comparative advantage, all of which must be considered for good integrated assessments.

Several recent studies illustrate the type of research that can contribute to the USGCRP impact assessment activities. Recent suggestions for improved impact assessment methodologies include those of Malone and Yohe (1992), who provide a framework for integrated regional assessment based on the MINK study; Robock et al. (1993), who describe new methods of generating impact analysis scenarios from general circulation model output; and Downing (1991) and Liverman (1990), who develop techniques for vulnerability assessment.

The MINK study used an analog climate from the 1930s to examine the impacts of climate change in the Midwest-Great Plains region (Missouri, Iowa, Nebraska, and Kansas) (Rosenberg et al. 1993). The study was integrated in that it looked at several sectors—agriculture, forests, water, and energy—and assessed the interindustry linkages and interacting impacts with a model of the regional economy. The effects of contemporary and future adaptations to climate (such as improved plant varieties) as well the agricultural impacts of higher CO₂ levels were assessed in the study. Several elements of the MINK framework could be applied to more complex regions and climate scenarios.

Another example of integrated impact assessment is the recent study by Rosenzweig and Parry (1994) of the potential effects of climatic change on world food supply. This study used a range of global warming scenarios to assess changes in crop yields and potential adaptations in 18 countries and integrated the impacts through a world food model. Linked models are also being used in an integrated assessment of the impacts of climate warming in the Mackenzie River Valley of northern Canada (Lonergran, DiFrancesco, and Woo, 1993; Cohen, 1992).

RELATION TO INTERNATIONAL RESEARCH

This research effort would support international efforts at assessing global change impacts and vulnerabilities through institutions such as the Intergovernmental Panel on Climate Change and regional research efforts such as the Inter-American Institute (IAI). It might also support the emerging HDP activity on Environmental Security and Sustainable Development.

IMPLEMENTATION ISSUES

This research initiative can advance through both investigator-initiated and institutionally coordinated research. Some of the research could be coordinated

through USGCRP contributions to international efforts such as the IAI and the proposed center for climate prediction. Links between physical scientists and social scientists are important to ensure that investigators are using the most relevant and up-to-date data and model results. Although agencies with responsibilities in specific sectors (e.g., water, agriculture) might sponsor related research, coordination will be required to further the potential of integrated assessments.

Understanding Population Dynamics and Global Change

There is a need for more fundamental understanding of the linkages between population processes and global environmental changes. Population growth, composition, and distribution have important interrelationships with land use, land cover, and global climate change. They also affect demand for other kinds of natural resources because, for any given combination of technology, energy use patterns, and social organization, population can have important multiplying effects in relation to global change. The need for policy responses to global change varies with the size, composition, and distribution of populations, and demand for policy responses is also affected by the populations that will feel the impacts of global change. Consequently, integrated assessment and policy analysis need to take into account the likely size and distribution of affected human populations.

The three fundamental processes determining population growth and distribution are fertility, mortality, and migration. All three processes are likely to affect and be affected by global change. In the short term (5 to 15 years), migration (both within and across national boundaries) is likely to be highly dynamic and correlated with global change. Shifts in population age structure may also have important effects on resource demand.

In considering population processes, it is imperative not to assume that causality flows in just one direction. Although some writers have treated population as an independent or exogenous variable in terms of its relationship to global change, environmental factors also influence population processes. For example, environmental quality, including climate, is one of the prime factors influ-

encing migration destination choices. Declining environmental quality and decreasing productivity of land may force people to move. Drastic environmental or climate change may also lead to increased mortality. Thus, it is important to conduct empirical research on both the effects of population dynamics on global change and of global change on population dynamics. In addition, it is important to recognize that relationships between population and global change can operate through or be mediated by other driving forces, such as economic or policy changes. For example, the effect of a resettlement program on an area may depend on the policies of the resettlement agency.

RELATION TO USGCRP PRIORITIES

The importance of population processes and trends is already well recognized. Population processes are a central interest of researchers on the human dimensions of global change. We place special emphasis on migration research because we see this as the most urgent need, and as readily linked to other global change research efforts. A focused research effort will support the wider needs of the USGCRP in the following ways:

- it will allow a clearer link between human migration and climatic changes. It will provide information on the likely human impacts of events predicted by climate models, identify model outputs of particular importance for impact studies, and possibly alter parameters used as inputs to climate models;
- it will provide important socioeconomic and population characteristics as inputs into land use models, thus improving the accuracy of forecasts from such models;
- it will provide inputs into models of demand for other environmentally relevant resources, including energy, water, agricultural chemicals, and manufactured goods, thus improving forecasts of burdens on the environment mediated by such demand; and
- it will assist the wider USGCRP initiative on integrated assessment by providing straightforward links between projected impacts and possible policy responses on one hand, and the size and distribution of affected populations on the other.

TIMELINESS OF EFFORT

Focused research on population and global change is particularly timely for at least the following reasons:

- the population research community has made significant advances toward understanding the relationship between population and socioeconomic change. These advances are the result of techniques and theories that integrate

multiple levels of analysis (macro and micro), reciprocal causation, and both qualitative and quantitative methodologies. Because of the prominent role of fertility in the concern over population growth over the past 25 years, scientific advances in this area have been strongest. The population research community is now ripe for similar advances in the migration area.

- substantial advances have been made in geographic information systems, which allow the merging of population data with other data using geographic location as a join point.

- geographic information systems allow the population research community to bring its considerable statistical, methodological, and theoretical skills to issues that heretofore have not been researchable. There is emerging activity within the population research community, as evidenced by the papers being presented at recent meetings of the Population Association of America and activities of the NRC's Committee on Population (Jolly and Torrey, 1993). In the past, the population research community sat on the sidelines when global change issues were discussed, and as a result demographic expertise was not brought into discussions of population and global change.

- examining the human dimensions of global change will require multidisciplinary research teams. The population research community has considerable experience with multidisciplinary research teams and can provide a model for other areas of research on human dimensions of global change.

RESEARCH GOALS

The following are examples of research topics that could be addressed in the short term:

1. To what extent do patterns of environmental change in agricultural areas affect migration? For example, does migration lead to increased urbanization or resettlement in other agricultural areas?

2. What are the interrelationships between migration processes on one hand, and climate, climate change, and the physical environment on the other? For example, knowledge of migrant characteristics and motivations may explain patterns of settlement abandonment and establishment during periods of climatic change.

3. How does the interaction between population growth and changes in technology and consumption patterns affect global environmental changes? For example, what combinations of these driving forces account for deforestation or for the trajectories over time of greenhouse gas emissions in different countries?

4. What is the role of the frontier in shaping migration patterns and household formation patterns? Modeling efforts in all these areas would include feedback loops.

In the longer term, research should also examine interrelationships of global change with human fertility and mortality processes.

RELATION TO INTERNATIONAL RESEARCH

The International Union for the Scientific Study of Population has a committee on population and the environment, which has been active with other international organizations in sponsoring research seminars. For example, in October 1994 it will hold a conference on population and the environment in arid regions, cosponsored with the International Geographic Union and the Population Division of UNESCO.

The HDP has identified research on demographic changes as an element of its research focus on Social Dimensions of Resource Use. Its plans include developing and experimenting with models of global scale that include population variables and developing methods for analyzing population-environment dynamics within particular countries. The research directions we identify here are quite compatible with the international plans for HDP, making it likely that U.S. research and international efforts will be mutually reinforcing.

IMPLEMENTATION ISSUES

The research program should represent a mix of institutional support and investigator-initiated research. Appropriate use of the advances being made in the general area of geographic information systems requires specialized hardware, software, and personnel that could not be funded on any single investigator-initiated research grant. This type of infrastructure should be made available through institutional support. At least 75 percent of the research funding in this area, however, should be made available through investigator-initiated research grants. Because this is a new area requiring multidisciplinary teams, it will be necessary at first to rely on Requests for Applications to generate high-quality proposals.

Much of the federally funded scientific research in the population area is funded through the Demographic and Behavioral Sciences Branch of the National Institute of Child Health and Human Development. Coordination between that agency and USGCRP is essential.

Conclusion

The scientific community has entered a new phase in its efforts to understand the human dimensions of global change. Earlier efforts succeeded in establishing human dimensions research as a coherent intellectual enterprise and a legitimate field of study for those desiring to advance understanding of the complex interactions among physical, biological, and social systems involved in global environmental change. What is more, a number of groups working largely independently have developed generally similar research agendas in this area, listing a variety of important topics concerning the human sources and consequences of global change and the probable responses of social systems to large-scale environmental change.

Now it is time to take the next steps in the scientific endeavor, establishing well-defined science priorities for human dimensions research and devising science and implementation plans for the highest-priority areas in the same way that such plans have been developed to guide major research programs in the natural science of global change. This report articulates selections of science priorities and proposes a strategy for developing science and implementation plans in a manner that is not only efficient but that also allows for input from a broad spectrum of members of the relevant communities of scientists and of research sponsors and consumers.

The research programs outlined here will contribute substantially to the increasingly important goals of conducting integrated assessments of global change issues and engaging in policy-relevant analyses of mitigation and adaptation strategies. Integrated assessment requires a concerted effort to understand all the

elements in a cycle, including anthropogenic sources of environmental change, earth system processes, the impacts of environmental change on social systems, and human responses to actual or anticipated impacts. To date, the USGCRP has emphasized the element of earth system processes in this cycle. Although this research remains crucial, the goal of end-to-end assessment calls for equally serious attention to the other elements of the cycle as well as a new emphasis on the feedback loops linking these elements. We believe that the research programs recommended here will contribute significantly to achieving this goal over the next 5 to 10 years.

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